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Research article

Comparative study of ground water treatment plants sludges to remove phosphorous from wastewater

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ABSTRACT

Alum- and iron-based sludge obtained from water treatment plant produced during a unit treatment process (coagulation and flocculation) have been widely tested as a low-cost adsorbent to remove phosphorous (P) from wastewater. However, the effectiveness of iron-based sludge generated from the oxidation of iron which naturally occurs in the ground water has not been investigated. Moreover, influences of dominant metals ions comprised in the treatment plants sludges on P adsorption capacity and rate from wastewater are not yet known. This study, therefore, employed four different groundwater treatment plants sludges iron-based (from the oxidation of iron) and alum-based (from coagulation and flocculation process) to determine their P adsorption capacities and adsorption rates from the synthetic wastewater (SWW) and secondary effluent wastewater (SEWW). Although metals ions concentrations were the highest in the iron-based sludge amongst the sludge used in this study, it appeared to have the lowest P adsorption capacity and adsorption rate. A good correlation between aluminium to iron mass ratio and adsorption capacity for both types of waters were noted. However, a poor relation between aluminium to iron mass ratio and adsorption rates for the SEWW was observed. Further, the tested sludges were found to have a better P removal efficiency and adsorption capacity from the SEWW than from the SWW. Thus, this study demonstrates the ground water treatment plants sludges could be a low cost and effective adsorbent in removing P from wastewater.

1. Introduction

Phosphorus (P) has been found to be a major contributor to Eutrophication. The eutrophication is described as the excessive algal growth resulting in the depletion of dissolved oxygen in the water bodies. Lack of sufficient dissolved oxygen results in the death of aquatic life and eventually deteriorates the quality of water bodies (Karageorgiou et al., 2007). Wastewater is a major source of P in the receiving water bodies during the disposal and thus, strategies to regulate P concentrations at the point of wastewater disposal have led to the development of various P removal strategies (Rashed et al., 2014).

Current methods utilised by wastewater treatment plants for P removal include chemical, biological and physical methods. Chemical methods focus on precipitation of P with the use of chemicals such as ferric chloride, alum and lime. Despite their effectiveness, they lead to expensive treatment methods due to high cost for purchasing chemicals and managing large volume of chemical sludge produced during the treatment process (Loganathan et al., 2014). Biological methods, usually implement in the secondary treatment stage are dependent on metabolic activities of P accumulating microbes. Although this method is effective, other factors such as complexities in operation (maintaining nutrients, temperature, aerobic and anaerobic conditions) and high-cost limit the widespread use of this process (Gebremariam et al., 2011). Physicochemical methods such as UV ray, membrane technology and electro-coagulation are also employed. These methods have also been found to be complex and costly due to the purchase and maintenance of high-end technologies in the treatment (Loganathan et al., 2014). Owing to the disadvantages of these methods of P removal, the need to investigate P removal using low-

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cost materials is essential.

Recent development of adsorption research in P removal from aqueous solutions has attracted the great attention. The key problem is to look for highly efficient and low-cost adsorbent. In the recent past, several low-cost and easily available materials and by-products such as zeolite (Wang et al., 2013), fly ash (Chen et al., 2007), blast furnace slag (Kostura et al., 2005), steel furnace slag (Barca et al., 2014; Xiong et al., 2008), aluminium-bentonite, iron-bentonite and aluminium-iron-bentonite (Yan et al., 2010), aluminium and iron oxides (Borggaard et al., 2005), industrial by-products (Habibiandehkordi et al., 2014) have been extensively investigated. Past studies (Razali et al., 2007; Babatunde et al., 2009; Ahmad et al., 2016) demonstrated using drinking water sludge, P could be removed from aqueous solutions. However, their effectiveness in removing P depends on chemical compositions and physical structures (Li et al., 2013). Depending on treatment process and source water quality, drinking water treatment plants produce wide verities of sludges and their capacity in removing P would not be the same. The successful application of water treatment sludge would not only provide a low-cost technological solution for P removal, but also provide an effective waste management option for drinking water utilities.

Characteristics of sludge generated from ground water treatment plants located in Western Australia could be different than other treatment plants due to the different in treatment processes employed, water sources and water qualities. For instance, some raw water sources contain very high concentration of iron but less dissolved organic carbon (DOC). In such condition, chlorine is dosed in the treatment plant to reduce iron concentration. On the other hand, if DOC concentration is high in the source water, then alum is used as a coagulant to reduce DOC level. Therefore, the treatment processes employed based on source water quality could produce verities of sludge and they could be rich in iron, aluminium or both. However, the effectiveness of iron-based sludge produced while removing iron through oxidation process is unknown. Further, no research has been conducted to determine the influence of dominant metals ions present in the sludge of ground water treatment plants in removing P from wastewater.

The objective of this study was to compare P adsorption capacity and adsorption rate of the sludge obtained from the groundwater treatment plants, representing different treatment processes and raw water qualities. This study was distinctive as it directly evaluated P removal capacity of the four different types of ground water treatment plants sludges (three alum-based and one iron-based) in batch experiments. The tests were carried out using the water treatment plants sludges (oven-dried) and synthetic wastewater (SWW) containing only P and the secondary effluent wastewater (SEWW).

2. Materials and methods

2.1. Sludge collection and preparation

Sludges used in this study were sourced from four different groundwater treatment plants named Plant-A (31.8762° S, 115.7989° E), Plant-B (32.1070° S, 115.8670° E), Plant-C (31.8630° S, 115.8700° E) and Plant-D (31.7417° S, 115.8532° E) located in Perth, Western Australia. Details of raw water characteristics prior to treatment are given in Table 1. Chlorination is carried out to remove iron from the raw water in Plant-A. No other treatment processes are employed in treatment plant-A and the sludge obtained from this treatment plant was termed as iron-based sludge. Alum is used as coagulant in other treatment plants (Plants-B, -C and -D) to reduce DOC level. Moreover, aeration and pre-chlorination are carried out to remove iron. Although iron concentration was significant in the sludges obtained from alum used treatment plants (Table 2), the sludge was defined as alum-based sludge in this study. Sludges produced from the Plants-A, -B, -C and -D were named as Sludge-A, Sludge-B, Sludge-C and Sludge-D, respectively.

The sludge as wet residuals, typically10 to 30% solids was collected from the sludge drying bed of each treatment plant and stored separately in 25 L high-density polyethylene containers. Sludge was then oven dried at 105 °C for a period of 24–48 h in aluminium bowls until it gets dried. All sludges used in the experiment were dried within a week of collection to minimize the change from amorphous to crystalline structure (Duffy and vanLoon, 1994), which ensured that the sludges had a maximum number of hydroxide sites available for adsorption. Before use in the experiments, the dried sludges were gently crushed using a mortar and pestle and separated using sieves. The crushed sludge passed from 600 μm and retained in 150 μm sieves were used to maintain similar size of sludge collected from different treatment plants.

2.2. Wastewater collection and preparation

Synthetic wastewater (SWW): P stock solution (5000 mg-PL^{-1}) was prepared by dissolving anhydrous potassium di-hydrogen phosphate (KH_2PO_4) salt in the reverse osmosis (RO) treated water. The RO treated water had DOC and conductivity of <0.1 mg L^{-1} and <1 mS cm^{-1}, respectively. The stock solution was then stored in a polyethylene bottle (1.5 L) in the refrigerator (4 °C). The stock solution was diluted with RO treated water to prepare P concentrations based on the specific requirement.

Secondary effluent wastewater (SEWW): SEWW was collected from one of the wastewater treatment plants (31.9490° S, 115.8270° E) located in Perth, Western Australia. The wastewater treatment plant was designed to biologically remove nitrogen and organic carbon from wastewater. Neither chemical nor biological methods were employed to remove P from wastewater. The characteristics of the SEWW were DOC: 12.0 mg L^{-1}, phosphate: 8.4 mg-P L^{-1} ammonia: 0.08 mg-N L^{-1}, nitrite: 0.02 mg-N L^{-1}, nitrate: 10.8 mg-N L^{-1}, pH: 7.3, and suspended solids: 6.7 mg L^{-1}.

2.3. Experimental plan

2.3.1. Adsorption test

To determine the maximum P adsorption capacity of the sludge, adsorption test was carried out by varying the initial P concentrations and keeping a constant weight of sludge similar to the method employed by Park and Polprasert (2008). The SWW (250 mL) with varying P concentrations (0, 50, 100, 150, 200, 300, 400, 600 mg-PL^{-1}) were placed into 500 mL conical flasks. pH 6 of the SWW was maintained using HCl (1 M) and NaOH (1 M). Each sludge of 2.5 g (particle size of 150–600 μm) was placed into the flasks. The flasks were then placed in an orbital shaker and agitated at a speed of 200 rpm for a period of 48 h. After 48 h, mixing was stopped and supernatant (10 mL) from each conical flask were collected and filtered through 0.45 μm filter paper (GE Water and Process Technologies). The experiment was conducted in duplicate and average of them was reported. Similar process was repeated for the SEWW. The varying initial P concentrations in the SEWW were maintained by adding the stock P solution (5000 mg-P L^{-1}).

2.3.2. Adsorption kinetic test

The SWW (500 mL) with 50 mg-PL^{-1} was prepared in six beakers and pH 6 of the SWW was adjusted using HCl (1 M) and NaOH (1 M). Afterwards, sludge (5 g) was added into each of the six beakers and the beakers contents were mixed at a constant speed of 100 rpm for 24 h. Supernatant (10 mL) was collected periodically